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# A Frequency Modulator
[周波数変調器]

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[What is Claimed is:]

[Claim 1]

A frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

an input part, which outputs a non-inverted signal and an inverted signal of said input signal;

a first laser part for frequency modulation, which is driven by said non-inverted signal of said input signal and generates frequency-modulated light with a center wavelength of λ1;

a second laser part for frequency modulation, which is driven by said inverted signal of said input signal and generates frequency-modulated light with a center wavelength of λ2;

a local oscillator laser part, which generates unmodulated light with a center wavelength of λ0;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local

oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

a mixing part, which mixes said signals outputted from said first and second light-to-electricity converting parts and outputs a beat signal having frequency difference between the outputted signals, wherein both of said center wavelengths λ1 and λ2 are placed in the side of the wavelength longer than said center wavelength λ0 or in the side of the wavelength shorter than said center wavelength λ0.

[Claim 2]

A frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

a branching part, which branches said input signal and outputs two branched signals;

a first laser part for frequency modulation, which is driven by one of said branched signals and generates frequency-modulated light with a center wavelength of λ1;

a second laser part for frequency modulation, which is driven by the other one of said branched signals and generates frequency-modulated light with a center wavelength of λ2;

a local oscillator laser part, which generates unmodulated light with a center wavelength of λ0;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

a mixing part, which mixes said signals outputted from said first and second light-to-electricity converting parts and outputs a beat signal having frequency difference between the outputted signals, wherein said center wavelengths λ1 and λ2 are respectively placed in the side of the long wavelength and in the side of the short wavelength interposing said center wavelength λ0.

[Claim 3]

A frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

a branching part, which branches said input signal and outputs two branched signals;

a first laser part for frequency modulation, which is driven by one of said branched signals and generates frequency-modulated light with a center wavelength of $\lambda 1$;

a second laser part for frequency modulation, which is driven by the other one of said branched signals and generates frequency-modulated light with a center wavelength of $\lambda 2$;

a local oscillator laser part, which generates unmodulated light with a center wavelength of $\lambda 0$;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

a combining part, which combines said signals outputted from said first and second light-to-electricity converting parts and outputs them, wherein both of said center wavelengths $\lambda 1$ and $\lambda 2$ are placed in the side of the wavelength longer than said center wavelength $\lambda 0$ or in the side of the wavelength shorter than said

center wavelength $\lambda 0$, and at the same time, in either case of the above, the center wavelengths of said signals from said first and second light-to-electricity converting part have the same values.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a frequency modulator, or more particularly, to a wideband frequency modulator, which uses the optical heterodyne method.

[0002]

[Prior Arts]

Conventionally, the FM modulator, which uses the optical heterodyne method, is known. This type of FM modulator is disclosed in "Optical Super Wide-band FM Modulation Scheme and Its Application to Multi-channel AM Video Transmission Systems", K. Kikushima et al., IOOC '95 Technical Digest, Vol. 5, PD 2-7, pp. 33-34.

/3

[0003]

Figure 7 is a block diagram illustrating the structure of the conventional FM modulator disclosed in the above described literature. The FM modulator of Figure 7 is comprised of laser part 2 for frequency modulation, local oscillator laser part 3 and light-to-electricity converting part 41.

[0004]

Next, the operation of the above described conventional FM modulator will be described. Laser part 2 for frequency modulation has a laser light source and gives input signal (electric signal) 10 to said laser light source as the driving electric current. As a result, a laser beam, which is intensity-modulated by input signal 10, is outputted from laser part for frequency modulation 2. When the laser beam is intensity-modulated, it generates so called frequency chirp. Therefore, the frequency of the laser beam, which is outputted from laser part for frequency modulation, is simultaneously modulated. The above described laser beam, wherein the frequency is modulated, is frequency modulated light 31. Local oscillator laser part 3 outputs local oscillator light 30 having a narrow linewidth. Light-to-electricity converting part 41 detects optical heterodyne by multiplexing frequency modulated light 31 and local oscillator light 30.

[0005]

By multiplexing frequency modulated light 31 and local oscillator light 30 and detecting optical heterodyne, it is possible to obtain beat signal 50 having a frequency difference between the two light signals as the output of light-to-electricity converting part 41. Here, since frequency modulated light 31 has its frequency modulated, beat signal 50 has also its frequency modulated to the degree of the frequency modulation of the light. The frequency modulation

index of beat signal 50 is determined based on the amount of the frequency chirp of laser part 2 for frequency modulation. Therefore, an extremely wideband frequency modulation signal, which cannot be obtained by frequency modulation by an electric circuit, can be obtained as beat signal 50.

[0006]

[Problem to be Solved by the Invention]

In the conventional frequency modulator having the above described structure, Carrier to Noise ratio (hereinafter called "CNR"), which is the performance of a frequency modulation signal, is increased as the degree of the frequency shift in laser part 2 for frequency modulation is increased. Also, the CNR is increased as the linewidths of the two light sources of laser part 2 for frequency modulation and of local oscillator laser part 3 are increased. The linewidths of these light sources are the parameters, which depend on laser and cannot be significantly changed due to the restricted use conditions. However, if the oscillation of input signal 10 for laser part 2 for frequency modulation is increased, it is possible to increase the degree of the frequency shift. Here, since a laser light source has a threshold property, if the oscillation of an input signal is increased to a certain degree or higher, distortion is generated. Therefore, there is a limit to increase of the oscillation of the input signal and it is difficult to further improve the CNR performance.

[0007]

Considering the above described problems, the objective of the present invention is to provide a frequency modulator, which can further improve the CNR performance.

[0008]

[Means to Solve the Problem and Effect of the Invention]

Invention 1 is a frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

an input part, which outputs a non-inverted signal and an inverted signal of said input signal;

a first laser part for frequency modulation, which is driven by said non-inverted signal of said input signal and generates frequency-modulated light with a center wavelength of $\lambda1$;

a second laser part for frequency modulation, which is driven by said inverted signal of said input signal and generates frequency-modulated light with a center wavelength of $\lambda2$;

a local oscillator laser part, which generates unmodulated light with a center wavelength of $\lambda0$;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser

part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

a mixing part, which mixes said signals outputted from said first and second light-to-electricity converting parts and outputs a beat signal having frequency difference between the outputted signals, wherein both of said center wavelengths $\lambda 1$ and $\lambda 2$ are placed in the side of the wavelength longer than said center wavelength $\lambda 0$ or in the side of the wavelength shorter than said center wavelength $\lambda 0$.

[0009]

According to invention 1, the first and second laser parts for frequency modulation do the modulating operations by the non-inverted signal and the inverted signal of the input signal, which have an inversion relationship. Therefore, the polarities of the frequency shifts of the light, which are outputted from the first and second laser parts for frequency modulation, have an inversion relationship. This inversion relationship is applied to the beat signals, which are outputted from the first and second light-to-electricity

converting parts. As a result, the frequency shift of the signal, which is outputted from the mixing part, is the sum of the frequency shift of the beat signal, which is outputted from the first light-to-electricity converting part, and the frequency shift of the beat signal, which is outputted from the second light-to-electricity converting part. Here, if the degree of the frequency shift of the beat signal, which is outputted from the first light-to-electricity converting part, and the degree of the frequency shift of the beat signal, which is outputted from the second light-to-electricity converting part, are the same, the degree of the frequency shift of the signal, which is outputted from the mixing part, is two times as much as that of the conventional FM modulator, which has one laser part for frequency modulation and one light-to-electricity converting part.

[0010]

As described above, according to invention 1, by using two pairs of laser parts for frequency modulation, the frequency shift of the output signal can be doubled compared with the conventional one and the CNR performance can be significantly improved.

[0011]

Invention 2 is a frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

a branching part, which branches said input signal and outputs two branched signals;

a first laser part for frequency modulation, which is driven by one of said branched signals and generates frequency-modulated light with a center wavelength of $\lambda 1$;

a second laser part for frequency modulation, which is driven by the other one of said branched signals and generates frequency-modulated light with a center wavelength of $\lambda 2$;

a local oscillator laser part, which generates unmodulated light with a center wavelength of $\lambda 0$;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

/4

a mixing part, which mixes said signals outputted from said first and second light-to-electricity converting parts and outputs

a beat signal having a frequency difference between the outputted signals, wherein said center wavelengths $\lambda 1$ and $\lambda 2$ are respectively placed in the side of the long wavelength and in the side of the short wavelength interposing said center wavelength $\lambda 0$.

[0012]

According to invention 2, the first and second laser parts for frequency modulation do the modulating operations based on the branched signals having the same waveform. Therefore, the polarities of the frequency shifts of each output light have the same relationship. However, since center wavelengths $\lambda 1$ and $\lambda 2$ of each output light are placed in the position below interposing center wavelength $\lambda 0$:

$\lambda 1 < \lambda 0 < \lambda 2$

or

$\lambda 2 < \lambda 0 < \lambda 1$,

the polarities of the frequency shifts of the beat signals, which are outputted from the first and second light-to-electricity converting parts, have an inversion relationship. As a result, the frequency shift of the signal, which is outputted from the mixing part, is the sum of the frequency shift of the beat signal, which is outputted from the first light-to-electricity converting part, and the frequency shift of the beat signal, which is outputted from the second light-to-electricity converting part. Here, if the degree

of the frequency shift of the beat signal, which is outputted from the first light-to-electricity converting part, and the degree of the frequency shift of the beat signal, which is outputted from the second light-to-electricity converting part, are the same, the degree of the frequency shift of the signal, which is outputted from the mixing part, is two times as much as that of the conventional FM modulator, which has one laser part for frequency modulation and one light-to-electricity converting part.

[0013]

As described above, according to invention 2, similarly to invention 2, by using two pairs of laser parts for frequency modulation, the frequency shift of the output signal can be doubled compared with the conventional one and the CNR performance can be significantly improved.

[0014]

Invention 3 is a frequency modulator, which converts an input signal into a wideband frequency modulation signal by the optical heterodyne method, characterized in that said frequency modulator is comprised of:

a branching part, which branches said input signal and outputs two branched signals;

a first laser part for frequency modulation, which is driven by one of said branched signals and generates frequency-modulated light with a center wavelength of $\lambda 1$;

a second laser part for frequency modulation, which is driven by the other one of said branched signals and generates frequency-modulated light with a center wavelength of λ2;

a local oscillator laser part, which generates unmodulated light with a center wavelength of λ0;

a first light-to-electricity converting part, which multiplexes said light outputted from said first laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal;

a second light-to-electricity converting part, which multiplexes said light outputted from said second laser part for frequency modulation and said light outputted from said local oscillator laser part, detects an optical heterodyne and converts said multiplexed light into a beat signal, which is an electric signal; and

a combining part, which combines said signals outputted from said first and second light-to-electricity converting parts and outputs them, wherein both of said center wavelengths λ1 and λ2 are placed in the side of the wavelength longer than said center wavelength λ0 or in the side of the wavelength shorter than said center wavelength λ0, and at the same time, in either case of the above, the center wavelengths of said signals from said first and second light-to-electricity converting part have the same values.

[0015]

According to invention 3, the first and second laser parts for frequency modulation do the modulating operations based on the branched signals having the same waveform. Therefore, the polarities of the frequency shifts of each output light have the same relationship. Furthermore, since the relationship among center wavelengths $\lambda1$, $\lambda2$ and $\lambda0$ is:

$\lambda1 = \lambda2 > \lambda0$

or

$\lambda1 = \lambda2 < \lambda0$,

the polarities of the frequency shifts of the beat signals, which are outputted from the first and second light-to-electricity converting parts, have also the same relationship. In this way, if the center frequencies are the same and the frequency shifts are the same, the oscillation of the signal, which is outputted from the combining part, is the sum of the oscillation of the beat signal, which is outputted from the first light-to-electricity converting part and the oscillation of the beat signal, which is outputted from the second light-to-electricity converting part. Here, if the oscillation of the beat signal, which is outputted from the first light-to-electricity converting part, and the oscillation of the beat signal, which is outputted from the second light-to-electricity converting part, are the same, the oscillation of the signal, which is outputted from the combining part, is two times as much as that

of the conventional FM modulator, which has one laser part for frequency modulation and one light-to-electricity converting part. Here, elements of noises in the beat signals, which are outputted from the first and second light-to-electricity converting parts, are also added to the above. Since these noises are changed at random, the oscillation of the elements of the noises after they are added is less than two-times the oscillation of the elements of the noises before they are added.

[0016]

As described above, according to invention 3, by using two pairs of laser parts for frequency modulation, the oscillation of the output signals can be doubled compared with the conventional one while the oscillation of the noises is kept at a low level, and the CNR performance can be significantly improved.

[0017]

[Preferred Embodiments of the Invention]

(1) Embodiment 1

Figure 1 is a block diagram illustrating the structure of the FM modulator of Embodiment 1 of the present invention. In Figure 1, the FM modulator of the present embodiment is comprised of input part 1, laser parts 21 and 22 for frequency modulation, local oscillator laser part 3, light-to-electricity converting parts 41 and 42, and mixing part 5. Here, local oscillator laser part 30

has a structure wherein two identical local oscillator lights can be outputted.

[0018]

Next, the operation of the FM modulator of Embodiment 1 having the above described structure will be described. Input part 1 generates non-inverted signal 11 and inverted signal 12 of input signal 10 and outputs them to laser parts 21 and 22 for frequency modulation respectively. Laser part 21 for frequency modulation outputs frequency-modulated laser light, that is, FM modulated light 31, based on non-inverted signal 11. Similarly, laser part 22 for frequency modulation outputs frequency-modulated laser light, that is, FM modulated light 32, based on inverted signal 12.

/5

Light-to-electricity converting part 41 multiplexes FM modulated light 31 from laser part 21 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, converts the light to electricity, detects optical heterodyne and outputs beat signal 51. Light-to-electricity converting part 42 multiplexes FM modulated light 32 from laser part 22 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, converts the light to electricity, detects optical heterodyne and outputs beat signal 52. Mixing part 5 mixes beat signals 51 and 52, which are respectively outputted from light-to-electricity

converting parts 41 and 42 and outputs said beat signals as output signals 60.

[0019]

Figure 2 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 1. In Figure 2, (a) shows the frequency spectrum of local oscillator light 30, (b) shows the frequency spectrum of FM modulated light 31, (c) shows the frequency spectrum of FM modulated light 32, (d) shows the frequency spectrum of beat signal 51, (e) shows the frequency spectrum of beat signal 52 and (g) shows the frequency spectrum of output signal 60.

[0020]

As described above, Figure 2(a) shows the frequency spectrum of unmodulated local oscillator light 30 with a center optical frequency of $\nu0$ (hereinafter, instead of the wavelength, the optical frequency is used). Also, Figures 2(b) and (c) respectively show the frequency spectrum of FM modulated light 31 with a center optical frequency of $\nu1$ and the frequency spectrum of FM modulated light 32 with a center optical frequency of $\nu2$.

[0021]

Light-to-electricity converting part 41 multiplexes FM modulated light 31 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 51, which is the element of the frequency of the difference between the two signals. Generally, elements other than the beat signals, for

example, elements of intensity modulation in FM modulated light 31, are eliminated through a filter. As a result, beat signal 51 has the frequency spectrum shown in Figure 2(d) and its center frequency becomes:

$f1 = \nu 1 - \nu 0$.

In reality, the temperature of the laser light source in laser part 21 for frequency modulation or local oscillator laser part 3 is controlled by AFC (automatic frequency control) so that the center frequency becomes f1. According to the structure of the present embodiment, since local oscillator laser part 3 also has an effect on the laser part 22 for frequency modulation, it is easier to control the optical frequency of, that is, the wavelength of laser part 21 for frequency modulation.

[0022]

Light-to-electricity converting part 42 also does the same operation as that of the above described light-to-electricity converting part 41. In other words, light-to-electricity converting part 42 multiplexes FM modulated light 32 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 52, which is the element of the frequency of the difference between the two signals. As a result, beat signal 52 has the frequency spectrum shown in Figure 2(e) and its center frequency becomes:

$f2 = \nu 2 - \nu 0$.

[0023]

Mixing part 5 mixes beat signals 51 and 52 thereby outputting output signal 60, which is the element of the frequency of the difference between the two signals. As a result, output signal 60 has the frequency spectrum shown in Figure 2(g) and its center frequency becomes:

$f3 = f2 - f1$.

Frequency f1 and frequency f2 are stabilized by AFC so that center frequency f3 can be maintained. As described above, frequency f1 and frequency f2 are preferably stabilized by AFC of laser part 21 frequency modulation or laser part 22 for frequency modulation. As a result, by controlling center optical frequencies ν1 and ν2 of FM modulated light 31 and 32, frequency f3 of output signal 60 is stabilized.

[0024]

Laser parts 21 and 22 for frequency modulation do the modulating operations by non-inverted signal 11 and inverted signal 12, which have an inversion relationship. Therefore, the polarities of the frequency shifts of FM modulated light 31 and 32 have an inversion relationship. This inversion relationship can be applied to beat signals 51 and 52. As a result, the frequency shift of output signal 60 is the sum of the frequency shifts of beat signals 51 and 52. If the frequency shifts of beat signals 51 and 52 are the same, the frequency shift of output signal 60 is two times as much as the

frequency shift of beat signal 51 or that of beat signal 52. In this case, the fluctuation of the frequency, which becomes the cause of noises of beat signals 51 and 52, is also added to the above. However, since the fluctuation is at random, even if it is added, the sum is less than two-times the fluctuation of the frequency before it is added.

[0025]

Here, according to Embodiment 1, the relationship between the optical frequencies is:

$\nu1 > \nu0$ and $\nu2 > \nu0$.

However, the same result can be obtained when the relationship is:

$\nu1 < \nu0$ and $\nu2 < \nu0$..

[0026]

As described above, according to Embodiment 1, by using two laser parts for frequency modulation, it is possible to double the frequency shift of the output signal thereby improving the CNR performance. Also, since center frequency f3 can be determined only by center optical frequencies $\nu1$ and $\nu2$ of FM modulated light 31 and 32, even if there is a certain fluctuation of center optical frequency $\nu0$ of local oscillator light 30, it does not have an effect on center frequency f3. Furthermore, the structure of Embodiment 1 can achieve the advantage that the intensity-modulated part of FM modulated light 31 and 32 is removed thereby eliminating the influence of the intensity-modulated part.

[0027]

(2) Embodiment 2

Figure 3 is a block diagram illustrating the structure of the FM modulator of Embodiment 2 of the present invention. In Figure 3, Embodiment 2 has branched part 7 instead of input part 1 of above described Embodiment 1 (see Figure 1). In Figure 3, since other structural components are the same as those of Embodiment 1, the same reference numbers are used for the corresponding components and their explanation is omitted. Embodiment 2 with the above described structure is different from Embodiment 1 in the relationship among center optical frequencies.

/6

[0028]

Next, the operation of the FM modulator of Embodiment 2 having the above described structure will be described. Branched part 7 branches input signal 10 into two and outputs branched signals 71 and 72. Laser part 21 for frequency modulation is driven by branched signal 71 and outputs FM modulated light 33. Similarly, laser part 22 for frequency modulation is driven by branched signal 72 and outputs FM modulated light 34. Light-to-electricity converting part 41 multiplexes FM modulated light 33 from laser part 21 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, detects optical heterodyne and outputs beat signal 53. Light-to-electricity converting part 42 multiplexes FM modulated

light 34 from laser part 22 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, detects optical heterodyne and outputs beat signal 54. Mixing part 5 mixes beat signals 53 and 54 from light-to-electricity converting parts 41 and 42 and outputs the beat signal as output signal 60.

[0029]

Figure 4 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 2. In Figure 4, (a) shows the frequency spectrum of local oscillator light 30, (h) shows the frequency spectrum of FM modulated light 33, (i) shows the frequency spectrum of FM modulated light 34, (j) shows the frequency spectrum of beat signal 53, (k) shows the frequency spectrum of beat signal 54 and (m) shows the frequency spectrum of output signal 60.

[0030]

As described above, Figure 4(a) shows the frequency spectrum of unmodulated local oscillator light 30 with a center optical frequency of $\nu0$. Also, Figures 4(h) and (i) respectively show the frequency spectrum of FM modulated light 33 with a center optical frequency of $\nu3$ and the frequency spectrum of FM modulated light 34 with a center optical frequency of $\nu4$.

[0031]

Light-to-electricity converting part 41 multiplexes FM modulated light 33 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 53,

which is the element of the frequency of the difference between the two signals. Generally, elements other than the beat signals, for example, elements of intensity modulation in FM modulated light 33, are eliminated through a filter. As a result, beat signal 53 has the frequency spectrum shown in Figure 4(j) and its center frequency becomes:

$f4 = \nu0 - \nu3.$

In reality, the temperature of the laser light source in laser part 21 for frequency modulation or local oscillator laser part 3 is controlled by AFC (automatic frequency control) so that the center frequency becomes f4. According to the structure of the present embodiment, since local oscillator laser part 3 also has an effect on the laser part 22 for frequency modulation, the optical frequency of, that is, the wavelength of local oscillator laser part 3 is stabilized at a steady value with satisfactory accuracy. Therefore, it is easier to control the optical frequency of the wavelength of laser part 21 for frequency modulation.

[0032]

Light-to-electricity converting part 42 also does the same operation as that of the above described light-to-electricity converting part 41. In other words, light-to-electricity converting part 42 multiplexes FM modulated light 34 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 54, which is the element of the frequency of

the difference between the two signals. As a result, beat signal 54 has the frequency spectrum shown in Figure 4(k) and its center frequency becomes:

$f5 = \nu 4 - \nu 0$.

[0033]

Mixing part 5 mixes beat signals 53 and 54 thereby outputting output signal 60, which is the element of the frequency of the difference between the two signals. As a result, output signal 60 has the frequency spectrum shown in Figure 4(m) and its center frequency becomes:

$f6 = f5 - f4$.

Frequency f4 and frequency f5 are stabilized by AFC so that center frequency f6 can be maintained. As described above, frequency f4 and frequency f5 are preferably stabilized by AFC of laser part 21 frequency modulation or laser part 22 for frequency modulation. As a result, by controlling center optical frequencies $\nu 3$ and $\nu 4$ of FM modulated light 33 and 34, frequency f6 of output signal 60 is stabilized.

[0034]

Laser parts 21 and 22 for frequency modulation do the modulating operations based on branched signals 71 and 72, which have the same wavelength. Therefore, the polarities of the frequency shifts of FM modulated light 31 and 32 have the same relationship. However,

center optical frequencies $\nu3$ and $\nu4$ of FM modulated light 33 and 34 have the relationship of:

$\nu3 < \nu0 < \nu4$,

interposing center optical frequency $\nu0$ (in terms of wavelengths, FM modulated light 33 has the longest wavelength while FM modulated light 34 has the shortest wavelength). Therefore, the polarities of the frequency shifts of beat signals 53 and 54 have an inversion relationship. As a result, the frequency shift of output signal 60 is the sum of the frequency shifts of beat signals 53 and 54. If the frequency shifts of beat signals 53 and 54 are the same, the frequency shift of output signal 60 is two times as much as the frequency shift of beat signal 53 or that of beat signal 54. In this case, the fluctuation of the frequency, which becomes the cause of noises of beat signals 53 and 54, is also added to the above. However, since the fluctuation is at random, even if it is added, the sum is less than two-times the fluctuation of the frequency before it is added.

[0035]

Here, according to Embodiment 2, the relationship between the optical frequencies is:

$\nu3 < \nu0 < \nu4$.

However, the same result can be obtained when the relationship is:

$\nu3 > \nu0 > \nu4$.

[0036]

As described above, according to Embodiment 2, by using two laser parts for frequency modulation, it is possible to double the frequency shift of the output signal thereby improving the CNR performance. Also, by setting the relationship among the optical frequencies as above, it is possible to replace input part 1 of Embodiment 1 with branched part 7, which as the function of branching input signal 10 thereby further simplifying the structure.

[0037]

(3) Embodiment 3

/7

Figure 5 is a block diagram illustrating the structure of the FM modulator of Embodiment 3 of the present invention. In Figure 5, Embodiment 3 has combining part 6 instead of mixing part 5 of above described Embodiment 2 (see Figure 3). In Figure 5, since other structural components are the same as those of Embodiment 2, the same reference numbers are used for the corresponding components and their explanation is omitted.

[0038]

Next, the operation of the FM modulator of Embodiment 3 having the above described structure will be described. Branched part 7 branches input signal 10 into two and outputs branched signals 71 and 72. Laser part 21 for frequency modulation is driven by branched signal 71 and outputs FM modulated light 81. Similarly, laser part 22 for frequency modulation is driven by branched signal 72 and outputs

FM modulated light 82. Light-to-electricity converting part 41 multiplexes FM modulated light 81 from laser part 21 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, detects optical heterodyne and outputs beat signal 91. Light-to-electricity converting part 42 multiplexes FM modulated light 82 from laser part 22 for frequency modulation and local oscillator light 30 from local oscillator laser part 3, detects optical heterodyne and outputs beat signal 92. Combining part 6 combines beat signals 91 and 92 from light-to-electricity converting parts 41 and 42 and outputs the beat signal as output signal 100.

[0039]

Figure 6 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 3. In Figure 6, (a) shows the frequency spectrum of local oscillator light 30, (n) shows the frequency spectrum of FM modulated light 81, (p) shows the frequency spectrum of FM modulated light 82, (r) shows the frequency spectrum of beat signal 91, (s) shows the frequency spectrum of beat signal 92 and (t) shows the frequency spectrum of output signal 100.

[0040]

As described above, Figure 6(a) shows the frequency spectrum of unmodulated local oscillator light 30 with a center optical frequency of $\nu 0$. Also, Figures 6(n) and (p) respectively show the frequency spectrum of FM modulated light 81 with a center optical frequency

of $\nu 5$ and the frequency spectrum of FM modulated light 82 with a center optical frequency of $\nu 6$.

[0041]

Light-to-electricity converting part 41 multiplexes FM modulated light 81 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 91, which is the element of the frequency of the difference between the two signals. Generally, elements other than the beat signals, for example, elements of intensity modulation in FM modulated light 81, are eliminated through a filter. As a result, beat signal 91 has the frequency spectrum shown in Figure 6(r) and its center frequency becomes:

$f7 = \nu 5 - \nu 0$.

In reality, the temperature of the laser light source in laser part 21 for frequency modulation or local oscillator laser part 3 is controlled by AFC (automatic frequency control) so that the center frequency becomes f7. According to the structure of the present embodiment, since local oscillator laser part 3 also has an effect on the laser part 22 for frequency modulation, it is easier to control the optical frequency of, that is, the wavelength of laser part 21 for frequency modulation.

[0042]

Light-to-electricity converting part 42 also does the same operation as that of the above described light-to-electricity converting part

41. In other words, light-to-electricity converting part 42 multiplexes FM modulated light 82 and local oscillator light 30, converts the light to electricity, detects optical heterodyne and outputs beat signal 92, which is the element of the frequency of the difference between the two signals. As a result, beat signal 92 has the frequency spectrum shown in Figure 6(s) and its center frequency becomes:

$f7 = \nu 6 - \nu 0,$

which is the same center optical frequency as that of beat signal 91.

[0043]

Combining part 6 sums up and combines beat signals 91 and 92 thereby outputting output signal 100. As a result, output signal 100 has the frequency spectrum shown in Figure 6(t) and its center frequency is f7, which is the same as the center frequencies of beat signals 91 and 92. Therefore, by controlling center optical frequencies ν5 and ν6 of FM modulated light 81 and 82, frequency f7 of output signal 100 is stabilized.

[0044]

Laser parts 21 and 22 for frequency modulation do the modulating operations based on branched signals 71 and 72, which have the same wavelength. Therefore, the polarities of the frequency shifts of FM modulated light 81 and 82 have the same relationship. Furthermore, since:

$\nu 5 > \nu 0$ and $\nu 6 > \nu 0$,

the polarities of the frequency shifts of beat signals 91 and 92 have also the same relationship. Therefore, if the center frequencies are the same and the frequency shifts are the same, the oscillation of output signal 100 is the sum of oscillation of beat signal 91 and the oscillation of beat signal 92. If the oscillation of beat signal 91 and the oscillation of beat signal 92 are the same, the oscillation of output signal 100 is two times as much as the oscillation of beat signal 91 or that of beat signal 92. Here, elements of noises of beat signals 91 and 92 are also added to the above. Since they are at random, the oscillation of the elements of the noises after they are added is less than two-times the oscillation of the elements of the noises before they are added.

[0045]

According to Embodiment 3, the relationship between the optical frequencies is:

$\nu 5 > \nu 0$ and $\nu 6 > \nu 0$.

However, the same result can be obtained when the relationship is:

$\nu 5 < \nu 0$ and $\nu 6 < \nu 0$.

[0046]

As described above, according to Embodiment 3, by using two laser parts for frequency modulation, it is possible to double the oscillation of the output signal thereby improving the CNR performance.

[Brief Description of the Drawings]

[Figure 1]

Figure 1 is a block diagram of the structure of the FM modulator of Embodiment 1 of the present invention.

[Figure 2]

Figure 2 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 1.

[Figure 3]

Figure 3 is a block diagram of the structure of the FM modulator of Embodiment 2 of the present invention.

/8

[Figure 4]

Figure 4 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 2.

[Figure 5]

Figure 5 is a block diagram of the structure of the FM modulator of Embodiment 3 of the present invention.

[Figure 6]

Figure 6 is a view showing a frame format of the frequency spectrums in each part of the FM modulator of Embodiment 3.

[Figure 7]

Figure 7 is a block diagram of the structure of the conventional FM modulator.

[Explanation of the Codes]

1: input part

2, 21 and 22: laser part for frequency modulation

3: local oscillator laser part

5: mixing part

6: combining part

7: branching part

10: input signal

11: non-inverted signal

12: inverted signal

30: local oscillator light

31-34, 81 and 82: FM modulated light

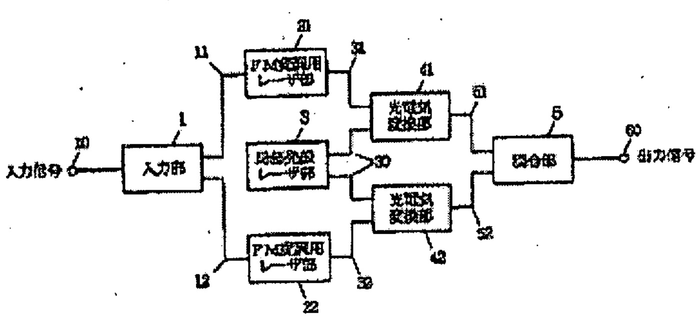
41 and 42: light-to-electricity converting part

50, 60 and 100: output signal

51-54, 91 and 92: beat signal

71 and 72: branched signal

【図1】




[Figure 1]

1: input part

3: local oscillator laser part

5: mixing part

10: input signal

21: frequency modulation laser part

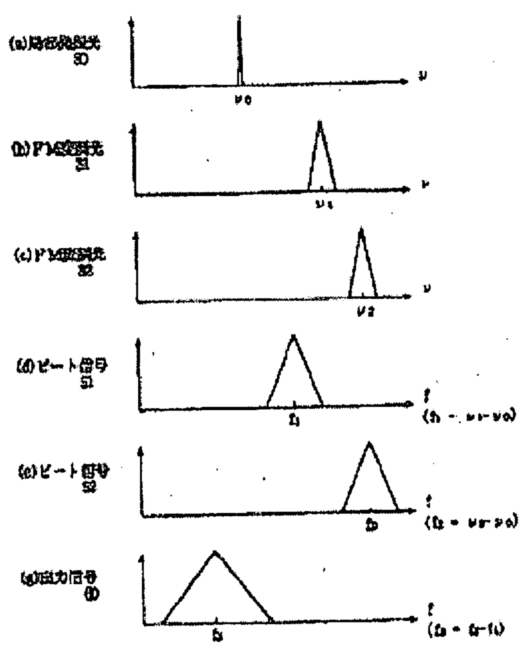
22: frequency modulation laser part

41: light-to-electricity converting part

42: light-to-electricity converting part

60: output signal

【図2】



[Figure 2]

(a) local oscillator light 30

(b) FM modulated light 31

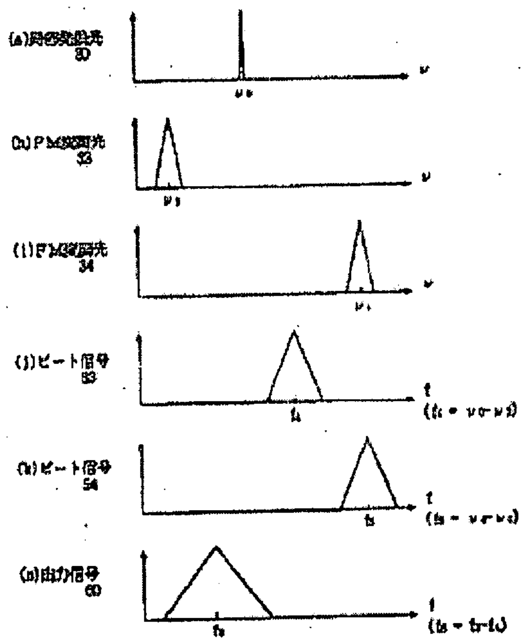
(c) FM modulated light 32

(d) beat signal 51

(e) beat signal 52

(g) output signal 60

【図4】



[Figure 4]

(a) local oscillator light 30

(h) FM modulated light 33

(i) FM modulated light 34

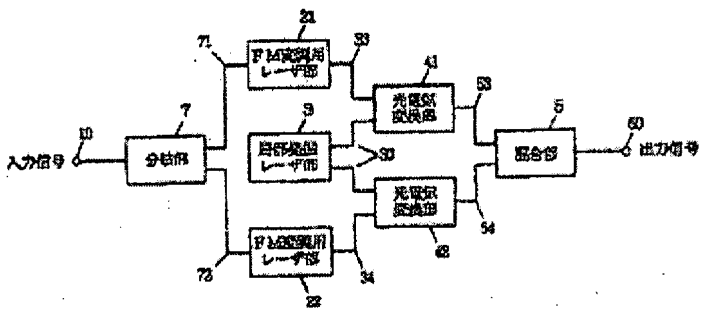
(j) beat signal 53

(k) beat signal 54

(m) output signal 60

/9

【図3】



[Figure 3]

3: local oscillator laser part

5: mixing part

7: branching part

10: input signal

21: frequency modulation laser part

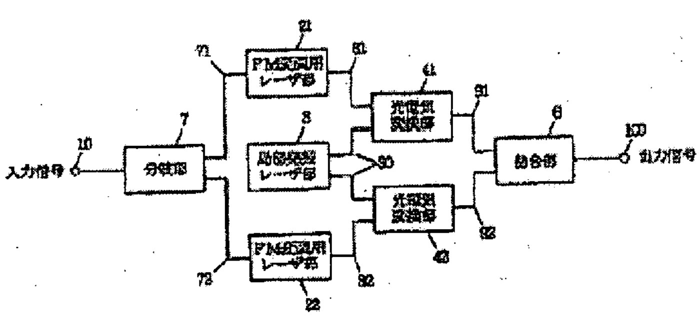
22: frequency modulation laser part

41: light-to-electricity converting part

42: light-to-electricity converting part

60: output signal

【図5】



[Figure 5]

3: local oscillator laser part

6: combining part

7: branching part

10: input signal

21: frequency modulation laser part

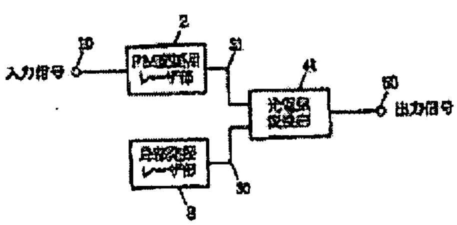
22: frequency modulation laser part

41: light-to-electricity converting part

42: light-to-electricity converting part

100: output signal

【図7】




[Figure 7]

10: input signal

2: frequency modulation laser part

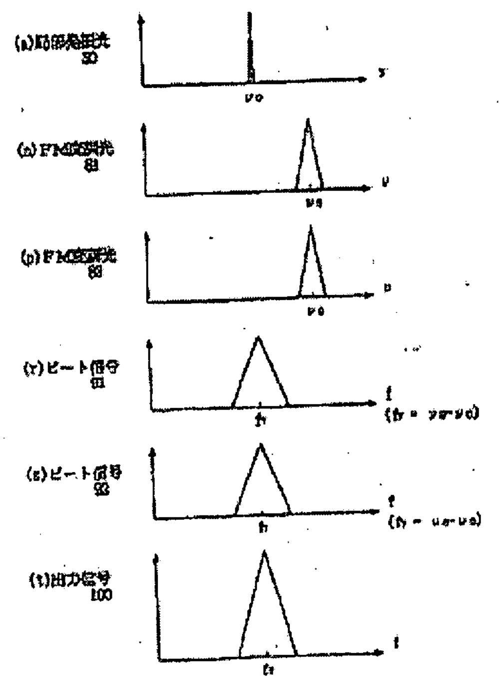
3: local oscillator laser part

41: light-to-electricity converting part

50: output signal

/10

【図6】



[Figure 6]

(a) local oscillator light 30

(n) FM modulated light 81

(p) FM modulated light 82

(r) beat signal 91

(s) beat signal 92

(t) output signal 100